MODELING SPACE LAUNCH PROCESS DELAYS TO IMPROVE SPACE VEHICLE ACQUISITION TIMELINES

Graduate Research Project

Lars Baldus
Lieutenant Colonel, GAF

Brian K. Yoshimoto
Major, USAF

Christopher M. Auger
Major, USAF

AFIT-ENV-GRP-13-J-01

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENV-GRP-13-J-01

MODELING SPACE LAUNCH PROCESS DELAYS
TO IMPROVE SPACE VEHICLE ACQUISITION TIMELINES

GRADUATE RESEARCH PROJECT

Presented to the Faculty

Department of Systems Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Engineering

Lars Baldus, Diploma d'Engineer, Electrical Eng., Lieutenant Colonel, GAF

Brian K. Yoshimoto, B.S. Aero. Eng., M.B.A. Business, Major USAF

Christopher M. Auger, B.S. Electrical Eng., M.S. Aerospace Mgmt., Major USAF

June 2013

AFIT-ENV-GRP-13-J-01

MODELING SPACE LAUNCH PROCESS DELAYS
TO IMPROVE SPACE VEHICLE ACQUISITION TIMELINES

Lars Baldus, Diploma d'Engineer, Electrical Eng., Lieutenant Colonel, GAF

Brian K. Yoshimoto, B.S. Aero. Eng., M.B.A. Business, Major USAF

Christopher M. Auger, B.S. Electrical Eng., M.S. Aerospace Mgmt., Major USAF

Approved:

Dr. John M. Colombi (Chairman) — 29 May 2013 (Date)

Lt Col J. Robert Wirthlin, PhD. (Member) — 29 May 2013 (Date)

AFIT-ENV-GRP-13-J-01

Abstract

United States Department of Defense (DoD) space acquisition programs almost always experience significant schedule growth, which closely correlates to cost growth. Even with the advent of more reliable launch vehicles, schedule delays often exceed 3 years and have the implication of reduced military or national security capabilities, significant increases in costs and occasionally program cancellations. This paper is intended to give acquisition professionals insight into the DoD's space launch process through modeling and simulation. It discusses the reasons a model is needed, outlining the perceived causes and resulting impacts of significant schedule growth from baseline planned launch dates to actual launch dates for satellites. This paper scopes the problem into a practical area of research, specifically from acquisition Milestone C through launch. Significant drivers to space vehicle timelines are the processes associated with scheduling launch support and conducting integration efforts for launch processing. Seven causal factors are identified as areas of delay. These factors are analyzed and assessed to draw conclusions about schedule growth and timeline considerations. The authors discuss the implications of these factors and hypothesize about lower-level contributors to create recommendations for those involved with space policy, acquisitions, and launch. Lastly, recommendations are provided to focus future research towards the identification of specific actions, which may be taken to reduce schedule delay occurring between Milestone C and the launch of a space system.

Acknowledgements

We extend sincere thanks to our professors and advisors in the Department of Systems and Engineering Management for their enduring leadership, feedback, and support during this research. Dr. John Colombi and Lt Col Robert Wirthlin provided invaluable guidance and mentoring as we progressed in this challenge. Thank you to the various subject matter experts who provided real-time expertise and advice from their vast experience at organizations such as the Space and Missile Systems Center (SMC), Aerospace Corporation, United Launch Alliance (ULA) and various system program offices. Most importantly, thank you to our families who encouraged us every step of the way.

Table of Contents

List of Tables

List of Figures

I. Introduction

1.1 Problem

United States Department of Defense (DoD) space acquisition programs are almost always plagued with significant unplanned schedule growth. Cost and schedule for required launch capabilities are determined early in the acquisition process based on requirements. An increase in space launch schedule affects not only the individual program, but often requires funding transfers from other space acquisition programs. This has the potential to affect all of the Department's space acquisition programs in terms of budget and schedule. The impact may even lead to the termination of one or more programs altogether.

The Government Accountability Office (GAO) conducted a study of multiple space programs in 2006 to determine the cause of increased costs to programs. Not surprisingly, the study revealed that, "…original cost [and schedule] estimates were particularly unrealistic about the promise of savings from increased contractor program management responsibilities, the constancy and availability of the industrial base, savings that could be accrued from heritage systems, the amount of weight growth that would occur during a program, the availability of mature technology, the stability of funding, the stability of requirements, and the *achievability of planned schedules*" (Government Accountability Office, 2006). Moreover, these factors are intricately tied to one another when assessed from the vantage point of a System Program Office (SPO). For example, the unavailability of mature technology leads to longer schedules while the necessary technology is developed.

An inconsistent industrial base may also cause parts availability issues, leading to longer acceptance times for simple components that now must be re-qualified for space flight. Even the reuse of heritage designs often requires rigorous testing at critical milestones with new technologies and designs to ensure performance and safety margins are still maintained for the system.

Since the 1970's the acquisition cost for space launch has increased dramatically. Many economic studies were conducted to better predict the cost for space launch based on historical data. While these studies helped predict actual costs more precisely they did nothing to prevent the overall acquisition cost for space launch from rising (Hertzfeld, 2005).

In the early 1990s, the United States suffered a series of critical setbacks with respect to national security. The cause of these setbacks was the failure of several satellite launch systems that were intended to support DoD and National Intelligence Community (IC) missions. In total, three Titan IV mishaps resulted in nearly $3 billion in fiscal losses, with two Air Force and one National Reconnaissance Office (NRO) satellites being lost. Additionally, the Delta III launch vehicle experienced two failures during commercial launches. Besides the launch failures, several in-flight anomalies occurred, casting a shadow of doubt on the Nation's ability to guarantee assured access to space (US Air Force, 1999).

As a result of unacceptable failure rates, the DoD introduced major changes in the risk posture associated with space launch. In August 2008, then Maj Gen Ellen Pawlikowski, Deputy Director of the NRO stated, "In the almost decade since the costly failures of the late 1990s, the Air Force Space and Missile Systems Center (SMC) and the

NRO have adopted a "back-to-basics" approach to mission assurance" (Pawlikowski, 2008). These changes, while intended to promote mission success and assured access to space, also had the unintended consequence of increasing costs and extending launch schedules.

In order to drive down cost and schedule impacts, the DoD generated a new approach to space launch. Boeing's Delta IV and Lockheed Martin's Atlas V launch vehicles became the crucible of our Nation's space launch capability for large DoD and IC satellites. This approach became known as the Evolved Expendable Launch Vehicle (EELV), and was intended to solve cost and schedule issues via competitive pricing and assured access to space on either of the two launch vehicles (Col R.K. Saxer et al, 2002).

In 2005, Boeing and Lockheed Martin formed the United Launch Alliance (ULA); the organization the DoD currently uses to contract Delta IV and Atlas V launch support (United Launch Alliance, 2013). Moreover, the DoD is actively pursuing the possibility of commercial space launch from vendors such as Space X, the company that has recently supported multiple resupply missions for the International Space Station (ISS).

Neither of these initiatives has shown the expected success or even a significant reduction in cost for space launch. Despite solid efforts, costs for space launch continue to rise. For example, the cost for NASA's recently scheduled Atlas V launch in November 2013 is currently estimated at $187 million in 2010 dollars. The exact same launch capability (NASA's MAVEN mission) was contracted three years earlier for the amount of $124 million in 2007 dollars (Clark, 2011).

1.2 Research Objective

The authors were tasked with understanding the implications of the space launch process on satellite acquisition timelines, with the intent of identifying critical aspects where changes may reduce schedule delays. Specific direction included the modification and extension of an existing model called the Enterprise Requirements and Acquisition Model (ERAM).

1.3 Boundary Conditions, Assumptions, and Constraints

The Space Launch Model was developed to understand delays plaguing a space program from Milestone C through launch. Within the model are several key assumptions and constraints. First, the model uses data only from EELV missions, since it is the primary launch capability for the United States DoD and NRO satellites. The data was collected from the Launch Information Support Network (LISN), and includes missions from June 2006 through March 2013. Two missions, the Defense Satellite Communications System (DSCS) IIIB-27 and IIIB-06, did not have any data entered into LISN and were subsequently ignored. No other EELV mission data was available in the database.

A constraining factor related to LISN is that the data was not captured in a standardized timeframe relative to each program. The data input was initiated relative to the initial launch request for a specific mission and did not indicate relative timing to key program dates such as Milestone C. In discussions with subject matter experts (SMEs), it was found this timeline could vary significantly based on the type of satellite program. Spacecraft maturity, constellation size, complexity, and budget certainty all impact the time it takes for a system to proceed from Milestone C to launch. As an example,

spacecraft implementing groundbreaking technologies and capabilities will take longer than the re-launch of already proven technologies, or multi-satellite procurement efforts such as the Advanced Extremely High Frequency (AEHF) and GPS programs. Differences arise due to launch vehicle types and configurations as well. Atlas V and Delta IV Medium launches are requested 2 years from the planned launch date while Delta IV Heavy missions are requested 3 years in advance. In an effort to simplify this issue, the authors elected to utilize a “black box” to simulate the time period immediately following Milestone C through the initial request for Launch Vehicle support. This method allows follow-on users to input the originally planned time for Milestone C to launch. For the purpose of this report all simulations were run with this “black box” removed, therefore indicating only delay time, not total time from Milestone C to launch.

Due to the inclusion of a foreign military officer in the research group, classification of data sources presented a significant constraint. While research did include generic information and unclassified mission names, it could not include specifics about the satellite designs for either DoD or NRO missions. This constraint was sufficiently mitigated by leveraging the authors’ experience in space acquisitions, as well as significant discussion with SMEs to generalize and interpret sensitive data.

Initially, the research focused on single-satellite and first-satellite-launched histories. The intent was to better understand the space vehicle schedule implications associated with a first-run satellite design. Unfortunately this data proved impossible to correlate, as classified programs do not indicate whether the satellite is a first run or reproduced satellite design. Additionally, the low number of satellite programs was deemed a concern by the authors and the researched sample set was increased to

incorporate timelines for programs in which multiple satellites launched, such as the Global Positioning System (GPS) IIF-2 and IIF-3.

Finally, the Extend Sim software used to create simulation models for both ERAM and the Space Launch process was unable to easily replicate a "negative delay" or schedule acceleration. In a few seldom cases, data indicated small accelerations, or "negative delay" in portions of satellite vehicle (SV) programs. Due to Extend Sim limitations, this data was modeled as "no delay" and is considered to have a negligible impact on the simulation results.

II. Literature Review

Extensive background research was completed to understand the acquisition process, specific space-system issues related to acquisitions, existing models of the acquisition process, and space-system launch processes. In excess of 40 policy documents, official instructions, journal articles, briefings, and acquisition models were reviewed to capture the space acquisition and launch processes. Unfortunately, no single document provided a concise overview or model of the space launch process. The sources referenced, as well as information gleaned from SMEs, were used to baseline the model. In order to produce the Space Launch Model, previous models of the acquisition process were reviewed. ERAM provided the modeling foundation of this effort and thus was a primary piece of literature reviewed. Additional significant documents included literature dictating the Current Launch Schedule Review Board (CLSRB) process, which is used to manifest all US launches. The history of launch was utilized to understand how the space launch process has evolved and is continuing to evolve in the current space acquisition environment.

2.1 ERAM

In 2008, ERAM was developed by Lieutenant Colonel J. Robert Wirthlin in an effort to understand key interactions between the Requirements generation (i.e. Joint Capabilities Integration Development System), Funding (i.e. Planning, Programming, Budgeting and Execution), and Acquisition Program portions of the DoD's organizational acquisition process from post-Milestone A through Milestone C. Wirthlin's model focused on the schedule implications of the process and interactions associated with each arm of the acquisition process, in an effort to identify critical

interactions that regularly led to significant schedule delays and proposed process or policy modifications that could be implemented to reduce schedules for acquisition programs. Specifically, Wirthlin focused on three primary questions: "How does the acquisition system work?", "Why does the system behave the way that it does?" and, "Are there things that can be done to improve the system?" (Wirthlin, 2009). Majors Leach and Searle extended ERAM in 2010 focusing specifically on space system acquisition efforts (Leach and Searle, 2010). Major Montgomery extended ERAM yet again in 2011 by modeling the rapid acquisition process often used by organizations such as the Special Operations Command (SOCOM) and the Rapid Capabilities Office (RCO) (Montgomery, 2011).

Due to the scope of ERAM it only modeled acquisition programs in the Technology Development and Engineering and Manufacturing Development phases, it did not model acquisition programs from Milestone C to an Initial Capability, Operational Capability, or in the case of this research, launch of a satellite. This posed significant problems for this research, as space program data is not consistently captured or is captured at higher classifications.

2.2 Space Launch Policy

The Air Force Space Command's (AFSPC) launch scheduling process guidance and lower echelon documentation was reviewed to ensure comprehensive understanding of the manifesting processes. The primary document which provided the information necessary to understand these processes was *Air Force Instruction (AFI) 10-1211, Space Launch Operations*. *AFI 10-1211* outlines the roles and responsibilities of the Air Force as the DoD Executive Agent for Space. Furthermore, it places the SMC Commander as

the sole focal point for certification of all DoD and NRO launch vehicles. Additionally, this document specifies that, "launch schedule execution will be based on national priorities," and designates AFSPC as the responsible agent for establishing the manifest for all DoD, Civil and commercial missions (Chandler, 2006).

2.3 Current Launch Schedule Review Board (CLSRB)

The launch manifest process is outlined in *AFSPCI10-1213_AFSPCGM1, Guidance Memorandum (GM) to AFSPCI 10-1213, Launch Scheduling and Forecasting Procedures* and *Air Force Space Command Long Range Launch Scheduling Process* (Weinstein, 2012, LeMaitre, 2005). These documents discuss the CLSRB process from the initial launch support request through launch for space systems. Specifically, *Air Force Space Command Long Range Launch Scheduling Process* outlines the National Launch Forecast (NLF) compilation in the 4-to-11 year future and how it flows into the Space Launch Manifest (SLM), which is a near-term, three year schedule for launches. The CLSRB is a body of stakeholders convened biannually to certify the next 18 months of the SLM (LeMaitre, 2005). *AFSPCI10-1213_AFSPCGM1* implements minor changes to the process by creating a series of Launch Commit Reviews (LCRs) to assess risk related to launch vehicle (LV) readiness, space vehicle (SV) readiness, ground/control system readiness, and operations readiness. It further delineates responsibilities between the SMC and 14th AF Commanders for each of these risk assessments, and assesses missions scheduled for the next 18 months (Weinstein, 2012). These documents demonstrate the importance of understanding launch scheduling with respect to the number of space missions requiring launch and the capability of the US launch industry.

2.4 Space Launch Assessments

The single most significant document related to evolution of the space launch process over the past 15 years is the *Space Launch Vehicle Broad Area Review (SLV BAR)*. The SLV BAR, led by Gen. Larry D. Welch, highlighted several problems with the space launch process which occurred in the 1990's. Specifically, the increase in launch failure rates from 1 per year over a 12 year period to 5 failures within 10 months. Mission assurance and quality incidents also raised from 18 in 200 launches to 9 in 51 launches, a 100% increase (US Air Force, 1999). The *SLV BAR* began a period of intense scrutiny related to launch vehicle mission assurance, but the added attention to detail and slower pace yielded strong success rates according to the article, *Assured Access to Space in a Competitive World* (Chilton, 2006). RAND, a non-profit research and analysis organization intended to improve policy and decision-making, highlighted additional issues with the space launch segment, discussing the ramifications of a reduced commercial launch requirement on the cost and schedule of government launches. These issues ultimately led to the combination of the Delta IV and Atlas V teams forming the United Launch Alliance to preserve the United States Evolved Expendable Launch Vehicle (EELV) heavy lift capability (RAND Corporation, 2006).

2.5 Space System Acquisition Delay Assessments

Multiple Government Accountability Office (GAO) reports were reviewed to assess current and historical space system schedules. The GAO conducts an annual assessment of acquisition programs. The "Defense Acquisition Assessment of Selected Weapons Programs" for years 2006 – 2012 were read to understand how space program schedules evolved over time and what the major contributing factors were. These GAO

reports repeatedly highlighted issues with technology, design, and production maturity for the spacecraft. Other issues included synchronization of space and ground segment activation, changes in prescribed program production rates, software-related delays, and fiscal and manning constraints (GAO, 2006-12).

In addition to a review of the GAO reports, the Launch Information Support Network (LISN) maintains a database of Launch Change Requests submitted after an initial request for launch support. This database was queried for all EELV missions and was used as the data from which all statistics were produced (AFSPC, 2013).

III. Methodology and Analysis

3.1 Process

Research was initiated by gaining a comprehensive understanding of the existing ERAM model created by Lt Col Wirthlin, as well as the extensions authored by Majors Searle, Leach, and Montgomery. A literature review was completed to determine existing policies relating to space launch, review studies documenting the space launch processes and how these subjects interact within the overarching DoD acquisition process.

The first major decisions determined how to model the critical portion of the launch process. The team assessed the space acquisition pre-Milestone C timeline was sufficiently modeled in the Searle and Leach extension to ERAM. Therefore the team chose to focus only on the post-Milestone C timeline. Additionally, it was deemed outside the scope of this research project to model the post-Milestone C timeline in as much intricate detail as the whole of ERAM. Eventually, the decision was made to model only the delays a space acquisition program is likely to face between Milestone C and launch, relative to the planned time from Milestone C to launch. Since planned timelines for individual programs vary greatly post-Milestone C, focusing only on timeline delay greatly simplified the modeling process. Additionally, as noted by multiple SMEs, program managers were more interested in identifying delays their programs may incur rather than another model of their already planned timeline. The addition of the "black box" mentioned previously will allow users to model the entire timeline from inception to launch, if desired. This will also allow for connection of the Space Launch Model to the larger ERAM model.

The team collected and assessed delays related to the space launch process associated with the Atlas V and Delta IV EELV. The authors developed a simple model of the space launch process using Grounded Theory Development and Inductive Reasoning Methods to gain further insight into key integration and decision points (Cal Poly, 2013).

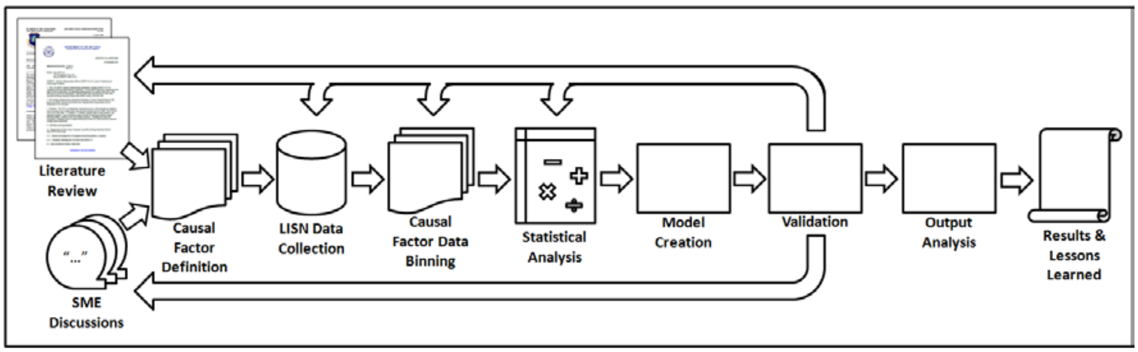


Figure 1: Methodology for the Development of the Space Launch Process Model

Data was gathered via discussions with SMEs from the SMC at Los Angeles Air Force Base, the NRO in Chantilly, Virginia, and other space-community locations throughout the United States. A total of 14 SMEs were utilized, included members from the acquisition process, Air Staff, the user community, various space SPOs, and the space launch community. Furthermore, SME volunteers ranged from government civilian, military, support contractors from the Aerospace Corporation, a Federally Funded Research and Development Corporation (FFRDC), and industry contract partners from the ULA. Most SMEs had 15 or more years in the industry, and some had as many as 30 years experience with the space launch process, including several active and retired senior military leaders. The SME discussions covered the full spectrum of the space launch process to include space launch requirements, budgeting, space vehicle integration, and launch operations.

The team drafted an initial description model based on author experience and relevant literature to guide discussions with SMEs. It was quickly determined the draft process was overly complicated and inaccurate in several areas. This led to a simpler delay based model focusing on SV-to-LV integration and the CLSRB manifesting process. Using data coding techniques, the team was able to discern seven primary categories of delay plaguing the space launch process post-Milestone C (Johnson, 2013). Those delay categories are described in Table 1.

Table 1: Taxonomy of Space Launch Delay Categories

Space Launch Delay Categories	
Delay Type	**Description**
Space Vehicle - Early (SV Early) (>18 months)	Delay initiated by the SV program office 18-months or more prior the predicted launch date. These delays typically have little impact on the ability to manifest a specific desired launch date at either Vandenberg AFB (VAFB) or Cape Canaveral Air Force Station (CCAFS).
Space Vehicle - Late (SV Late) (<18 months)	Delay initiated by the SV program office within 18-months of the current predicted launch date. These delays often impact the ability to manifest a desired launch date at either Vandenberg AFB or Cape Canaveral AFS, depending on manifest density. The SV late delays were often of shorter duration than SV early delays, leading to a separate distribution.
Launch Vehicle - Long Term (LV Long) (>18 months)	Delay initiated by the launch vehicle or associated leadership due to known manufacturing issues, launch separation requirements, or updates to an Initial Launch Capability (ILC) for the specific mission. These delays typically have little impact on the ability to manifest a specific desired launch date at either Vandenberg AFB or Cape Canaveral AFS.
Launch Vehicle - Short Term (LV Short) (<18 months)	Delay initiated by the launch vehicle or associated leadership due to unforeseen issues with the launch vehicle, near-term launch date change requests by the mission integrator, or a launch vehicle anomaly on a previous mission that has a ripple effect on the mission of interest. These delays may impact the ability to manifest a desired launch date at either Vandenberg AFB or Cape Canaveral AFS, depending on manifest density.

Re-queue	Delay or, in seldom cases, acceleration encountered when a program attempts to re-enter the launch manifest after it was removed due to another delay such as SV-Early. This occurs more often as the re-entry attempt is closer to the planned launch date, generally within 18 months.
Priority	Delay or acceleration of the launch date due to mission priorities. This occurs when the CLSRB process or senior leadership determines a launch date must slip or in seldom cases move earlier to accommodate mission requirements.
Weather / Miscellaneous (Wx / Misc.)	Delay of relatively short duration caused by weather, launch window refinement, or launch range support issues.

After review of the various individual delays space acquisition programs incurred relative to planned timelines, patterns began to develop. Delays either occurred for similar reasons, at similar times within the planned timeline or were due to common external factors. This led to the creation of the above common and general categories. These categories aided in simplifying the following model and provided a venue for later analysis. Most significantly, data coding ensured individual categories fit somewhat common and manageable distributions for inclusion into the resulting model.

Once the high-level categories were identified and defined, historical data was collected from the LISN database maintained by the Launch, Ranges and Networks Division of Air Force Space Command Headquarters. Data was collected from the LISN database by searching for all previous EELV missions, which resulted in data availability from June 2006 through March 2013. In total, the search resulted in 35 Atlas V and Delta IV missions (16 Delta IV and 19 Atlas V). Two missions, DSCS IIIB-27 and IIIB-06, didn't have any data entered into LISN and were subsequently ignored. The final dataset included 33 missions with a complete historical record of launch date changes and

causes for these changes. Each mission history yielded many Launch Change Request (LCR) data inputs, ranging from as few as four LCRs to as many as 32 LCRs. The team then binned the individual delays found on LISN into the most appropriate category, and separated them by launch vehicle type (Atlas vs. Delta) to allow for statistical analysis.

As mentioned previously, SME discussions indicated a potential difference between the space launch timelines associated with Atlas and Delta missions. Specifically, it was believed the Launch Vehicle Long Term, Launch Vehicle Short Term, Re-queuing, and possibly the Priority delays were dependent upon the launch vehicle type and associated reliability and launch rates. Delays related to the space vehicle, both early and late, as well as weather and miscellaneous delays were expected to be launch vehicle agnostic.

Microsoft Excel was used to consolidate and manipulate data. LCRs were reviewed and manually grouped into one of the seven delay category bins. Once all mission data was binned, each delay category was assessed to determine whether a statistical difference existed between delays associated with the Atlas V and Delta IV launch vehicles. The statistics gathered for each of these groups of data included the mean, median, mode, minimum, maximum, and standard deviation of the average delays by delay category, as shown in Table 2.

Upon examination of the data, the research team found the delay categories did not appear significantly different based on the launch vehicle type; a direct contradiction to expectations from SME discussions. A t-test was completed against the null hypothesis that the Atlas and Delta sample means were equal for each factor. The t-statistic was calculated using the average length of delay in each category for a specific

LV, X_n, the number of delays, n, and the variance of those delays, S^2. The degrees of freedom were calculated using the Smith-Satterthwaite method of calculation (Milton & Arnold, 2003). The t-statistic and Smith-Satterthwaite Degrees of Freedom equations are shown below:

$$t - statistic = \frac{(\overline{X}_1 - \overline{X}_2) - (\mu_1 - \mu_2)}{\sqrt{(S_1^2 / n_1) + (S_2^2 / n_2)}} \tag{1}$$

$$\gamma = \frac{[S_1^2 / n_1 + S_2^2 / n_2]^2}{\frac{[S_1^2 / n_1]^2}{n_1 - 1} + \frac{[S_2^2 / n_2]^2}{n_2 - 1}} \tag{2}$$

Table 2: Initial Statistics of Launch Delay Categories

Atlas Delay Category Statistics (Months)							
	SV-Early	**SV-Late**	**LV-Long**	**LV-Short**	**Re-queue**	**Priority**	**Wx/Misc**
Sample Size	25	83	32	28	31	15	17
Probability of Delay within Category	0.58	0.89	0.63	0.68	0.68	0.47	0.42
Average Delay	3.77	1.18	1.22	0.50	1.75	1.87	0.14
Median	3.03	0.46	0.64	0.25	0.43	0.76	0.03
Std Dev	3.99	2.84	2.62	0.63	2.20	4.73	0.20
Min Delay	-3.09	-5.46	-1.22	0.03	-0.10	-4.38	-0.03
Max Delay	10.99	15.33	14.05	2.57	6.97	12.99	0.72

Delta Delay Category Statistics (Months)							
	SV-Early	**SV-Late**	**LV-Long**	**LV-Short**	**Re-queue**	**Priority**	**Wx/Misc**
Sample Size	20	24	41	28	24	11	10
Probability of Delay within Category	0.58	0.89	0.63	0.68	0.68	0.47	0.42
Average Delay	4.40	1.09	1.85	0.62	2.30	2.35	0.24
Median	2.99	0.81	1.22	0.12	1.25	2.04	0.05
Std Dev	7.68	1.33	2.35	1.64	2.85	3.26	0.52
Min Delay	-1.02	-0.95	-4.05	0.03	-0.30	-2.53	0.03
Max Delay	35.00	4.18	8.98	8.75	11.18	8.98	1.71

Due to the hypothesis structure of this specific t-test, any p-values above 0.05 indicate the null hypothesis cannot be rejected, and therefore the data is assumed to have similar means. The p-values, shown in table 3, are all greater than 0.05, and demonstrate that the Atlas and Delta average delays cannot be distinguished from one another, at a 0.05 level of significance. Results of t-test comparison are shown in Table 3.

Table 3: T-Test of Atlas and Delta Delay Categories

	SV-Early	SV-Late	LV-Long	LV-Short	Re-queue	Priority	Wx/Misc
T Statistic	-0.3305	0.2197	-1.0600	-0.3645	-0.7885	-0.3094	-0.5674
P-Value	0.7436	0.8266	0.2932	0.7177	0.4349	0.7597	0.5818

Based on the results above, the first significant finding is that: *There is no significant statistical difference in the mission-level space launch delays associated with the Delta IV and Atlas V launch vehicles*. Based on the finding that no statistical difference existed between EELV launch vehicle types, the data was consolidated into a single grouping for all further analysis, as shown in Table 4.

The team then determined a plan to model the individual delays within the Extend Sim discrete modeling tool. The goal was to create an accurate simulation while focusing on simplicity and minimizing the introduction of error. The decision was made to model each of the seven delay categories in series using a double loop for each delay type. All delays were modeled separate from of one another. An example is shown in Figure 2. The seven individual delays were programmed within Extend Sim in series as an entire simulation segment, as shown in Figure 3.

Table 4: Overall Launch Delay Statistics

Overall Launch Delay Statistics for 33 Programs (Months)							
	SV-Early	SV-Late	LV-Long	LV-Short	Requeue	Priority	Wx/Misc
Sample Size	45	107	73	56	55	26	27
Probability of Delay Within Category	0.51	0.73	0.67	0.61	0.67	0.58	0.42
Average Delay	4.05	1.16	1.57	0.56	1.99	2.07	0.18
Median	3.03	0.49	0.72	0.21	0.82	1.00	0.03
Std Dev	5.85	2.58	2.47	1.23	2.49	4.10	0.35
Min Delay	-3.09	-5.46	-4.05	0.03	-0.30	-4.38	-0.03
Max Delay	35.00	15.33	14.05	8.75	11.18	12.99	1.71

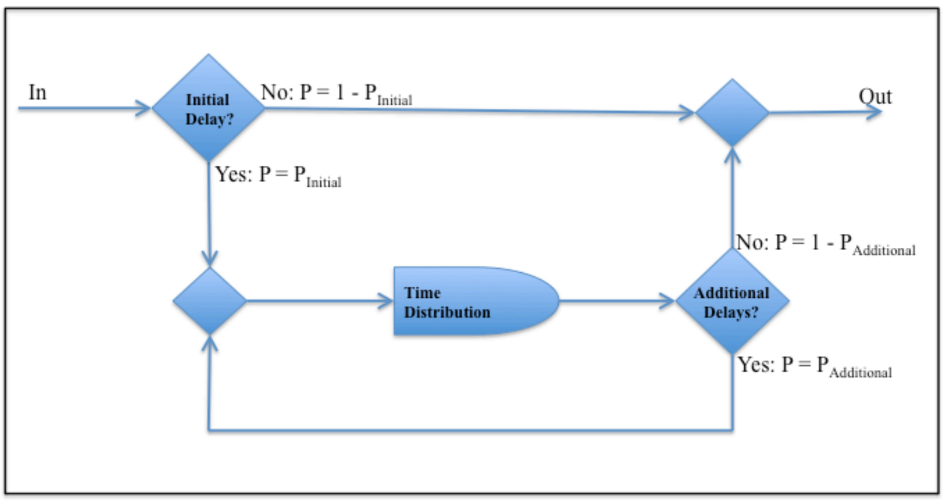


Figure 2: Example of Individual Delay Category Loop

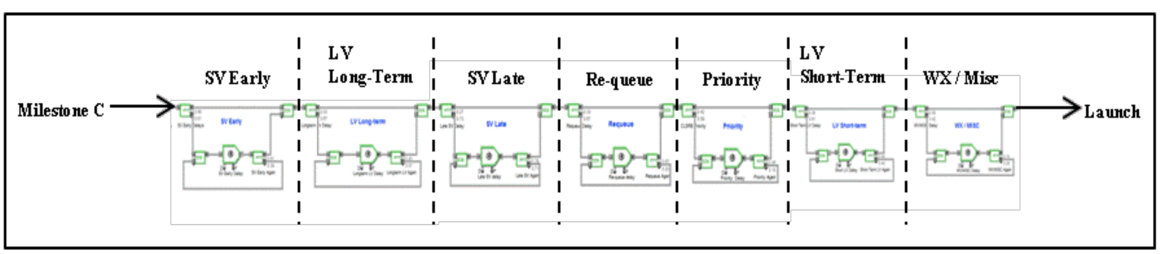


Figure 3: Model as Depicted in Extend Sim

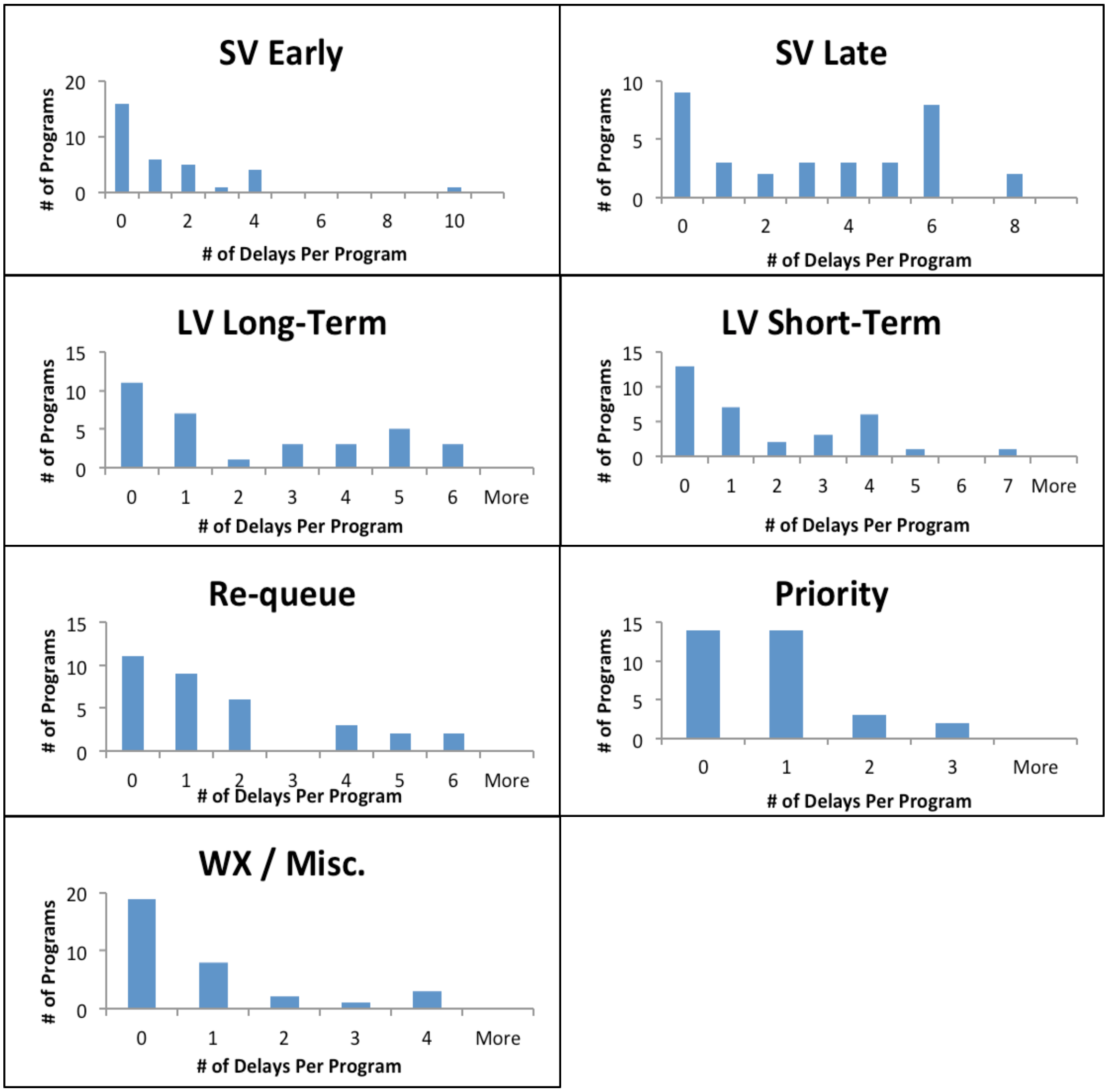


Figure 4: Histograms of Individual Delay Category Occurrences

The initial probability block setting for each category was determined by dividing the number of programs that experienced the particular delay by the total number of programs. This determined the probability a particular program would initially delay within a particular category. This calculation, shown below, was derived using data found in Table 5.

$$P_{initial} = \text{\# of programs delayed in category / \# of total programs} \quad (3)$$

If a program did encounter an initial delay the second probability block determined the probability of additional delays within the same category. This probability was calculated by dividing the average number of additional delays (average number of total delays per program per category, minus 1) into the number “1”, and subtracting this quotient from “1”. This calculation is shown below and was derived using data found in Table 5. This approximation was accurate when the average number of additional delays was greater than one. In the two cases when it wasn’t, Priority and Wx / Misc, the team used experience to estimate the probability an additional delay would occur. This structure established the secondary loop which determines how many times a particular program will experience a particular delay.

$$P_{additional} = 1 - \{1 / [(\text{avg \# of delays per program per category}) - 1]\} \quad (4)$$

The actual time delays themselves were simulated in Extend Sim using activity blocks. The activity blocks simulate a time delay via a randomly seeded sampling of a pre-assigned distribution. Each pass through the activity block simulates an individual delay occurrence, and then flows into the additional probability block to determine if another iteration of the delay will occur. If not, it will flow on to the next delay category loop, as depicted above in Figure 2.

Table 5: Overall Delay Occurrence Statistics

Delay Occurrence Probability Data							
	SV-Early	**SV-Late**	**LV-Long**	**LV-Short**	**Requeue**	**Priority**	**Wx/Misc**
# of "No Delay"	16	9	11	13	11	14	19
Total Programs	33	33	33	33	33	33	33
Probability of First Delay ($P_{initial}$)	0.51	0.73	0.67	0.61	0.67	0.58	0.42
1 - $P_{initial}$	0.49	0.27	0.33	0.39	0.33	0.42	0.58
(Average of "Non-0" Delays) - 1	1.64	3.45	2.31	1.80	1.50	0.36	0.92
Probability of Additional Delays ($P_{additional}$)	0.61	0.29	0.43	0.56	0.67	0.85	0.75

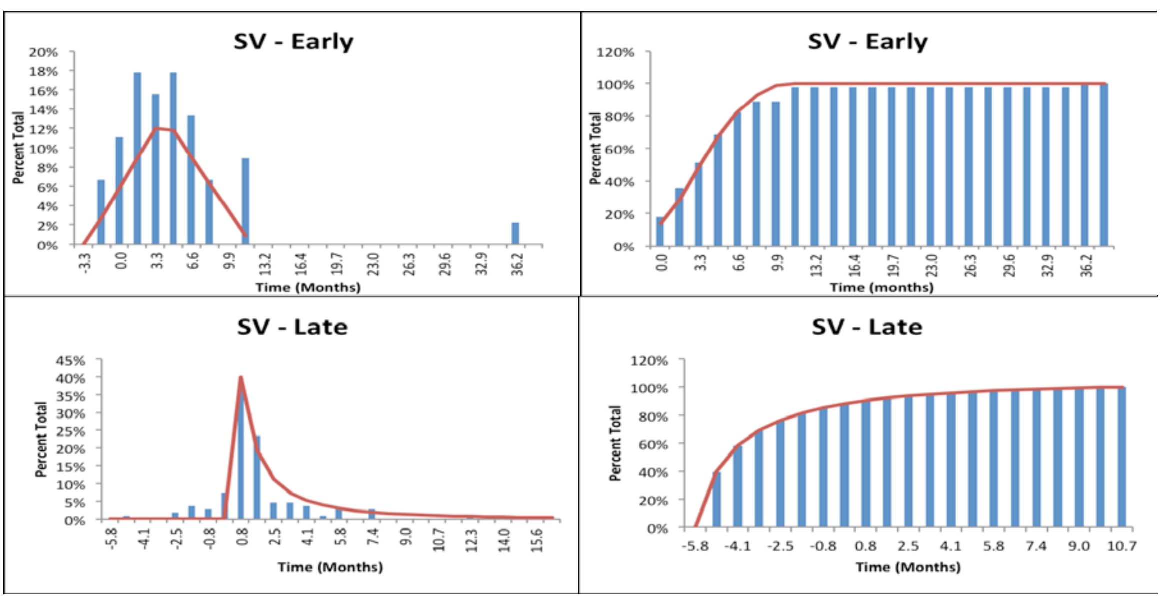
The researchers chose the proper distributions for each activity block after analysis of the actual program delay data. Statistical analysis was conducted on each delay category's actual data. These statistics are posted above in Table 5. Histograms were created detailing the time distribution of actual delay data per category. Probability density functions (PDFs) were chosen to best approximate the histogram data. In most cases the Inverse Gaussian function most closely approximated the delay data. Microsoft Excel add-in "Solver" was used to minimize the cumulative squared error between the histogram data and the distribution by optimizing the Inverse Gaussian parameters, α and β. The following equation describes this technique. Where α and β are input parameters to the Inverse Gaussian function, F_i is the Cumulative Distribution Function (CDF) evaluated at the corresponding histogram point i, H_i is the particular histogram value and N is the total number of histogram points.

$$\min_{(\alpha,\beta)} \sum_{i=1}^{N} (F_i - H_i)^2 \qquad (5)$$

Two particular delay category histograms, “SV – Early” and “Priority,” did not closely fit an Inverse Gaussian distribution, or any other distribution available in Extend Sim. In these cases simple triangular distributions were used, with minimum, maximum and most likely values set by observation, excluding statistical outliers (Evans, 2000). The distribution parameters used in the model are shown in Table 6 below. The histograms for each delay category along with the selected overlying distributions, in both PDF and CDF format are shown below in Figure 5.

Table 6: Delay Category Distribution Parameters

Distribution Type					
	Inverse Gaussian		**Triangular**		
Delay	**α**	**β**	**Minimum**	**Maximum**	**Most Likely**
SV - Early			-3	12	4
SV - Late	1.2	3			
LV – Long Term	1.1	1.8			
LV - Short Term	0.01	0.1			
Re-queue	0.59	4.97			
Priority			-4	10	1.3
Wx / Misc	0.152	0.159			



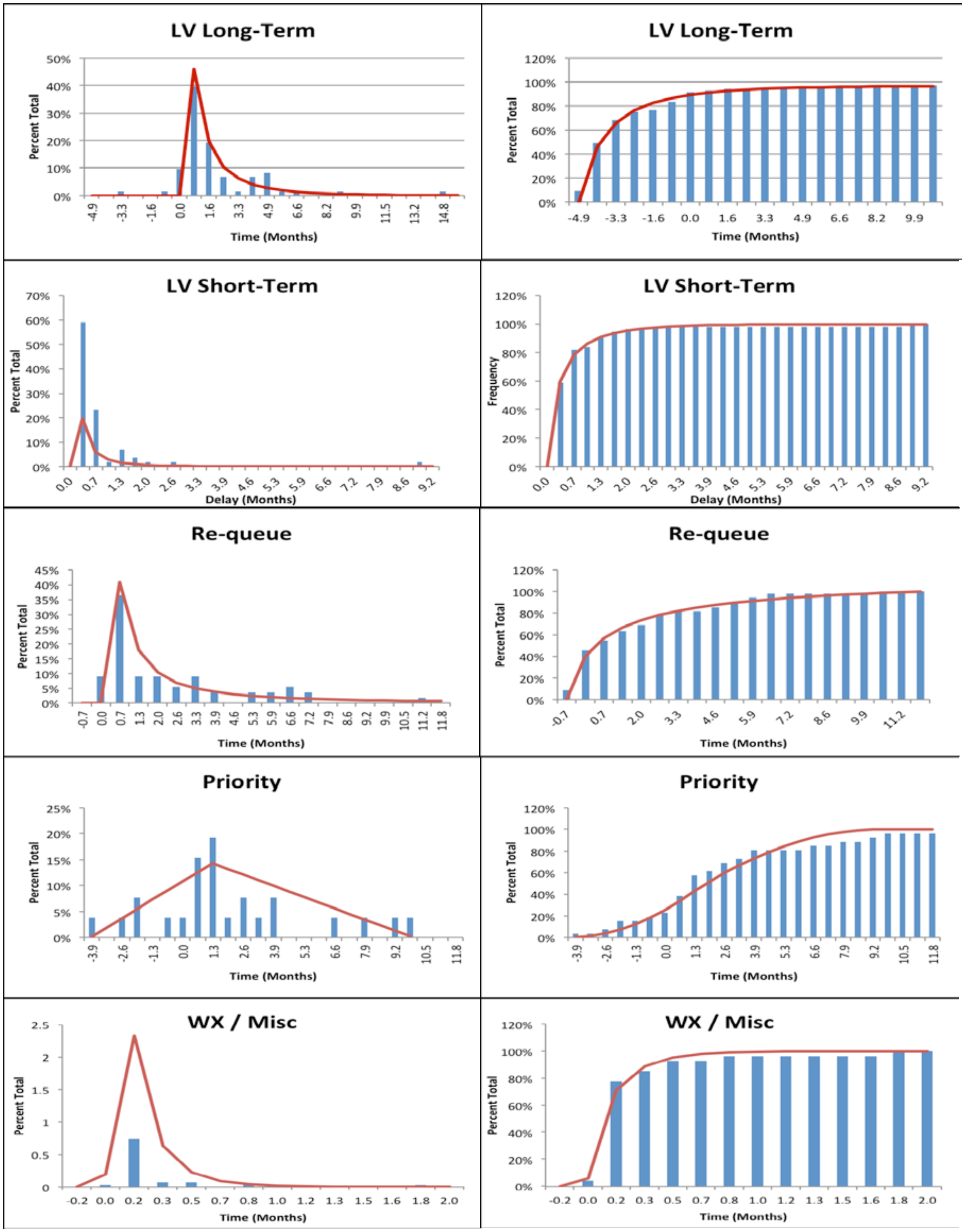


Figure 5: Delay Category Histograms with Distributions in PDF and CDF Format

In order to determine the number of Monte Carlo replications, R, required to achieve the relative precision, ε, of .05, at a significance level, α, of .05, the team employed the following equation. S_o is the sample standard deviation relative to the mean. The degrees of freedom, df, are equal to 32, one less than the sample size of 33 programs. This calculation references the Student T distribution.

$$R = (T_{\alpha/df})^2 S_o^2 / \varepsilon^2 \tag{6}$$

From this calculation, it was found that 473 replications were required. Therefore all experiments were completed using 1000 simulations, based on the simulation time available and the relative precision achieved.

3.2 Verification

The team verified the model by comparing two criteria between actual and modeled data. The first element compared was the average number of times a program or simulation experienced the individual delay categories. This assessment was used to verify the accuracy of the probability blocks used to simulate delay occurrences, and is shown below in Table 7 below. In each delay category the model simulations experienced fewer occurrences on average than the actual programs. This difference ranged from 16 – 41% amongst the delay categories. The team considered this difference substantial, but accepted it as within reasonable error bounds given the variance of the sample data and relative accuracy of the overall simulation results.

While the method used was statistically sound, it most likely underestimated the number of delay occurrences because multiple delays were simulated using only two

probabilities, $P_{initial}$ and $P_{additional}$. This technique was used to simulate the potential for many delays, while minimizing overall complexity and maximizing flexibility within the model. The error had a "delay shortening" affect on the overall model results. Additionally, Inverse Gaussian distributions were used to simulate most of the actual delay categories. This caused an unrealistically long delay to be occasionally, but rarely, encountered due to the infinitely long "tail" of the distribution. Regardless of this "delay lengthening" affect, Inverse Gaussian distributions still provided the best fit.

The team assessed the combination of the above discussed "delay shortening" occurrence estimation error and the "delay lengthening" distribution error actually combined to form an accurate end result. For these reasons, the team chose to accept these errors. The team recommends future work focusing on reducing or negating these errors altogether in future models.

Table 7: Model vs. Actual Delay Occurrences

Comparison of Model vs. Actual Delay Occurrences							
	SV-Early	**SV-Late**	**LV-Long**	**LV-Short**	**Requeue**	**Priority**	**Wx/Misc**
Actual Avg # of Delays per Prgm	1.36	3.24	2.21	1.70	1.67	0.79	0.82
Model Avg # of Delays per Prgm	0.80	2.49	1.56	1.20	0.99	0.66	0.58
Difference	41%	23%	29%	29%	41%	16%	29%

The overall simulation results were compared by basic statistical methods as well as the Kolmogorov-Smirnov (KS) test for like distributions. Results of the basic statistics are shown below in Table 8. The average program delay between actual and modeled data is within 1% with a standard deviation of 4%. The maximum result of the model is 34% longer than the actual data; this result was expected due to the cumulative usage of

Inverse Gaussian functions and the "infinite, but highly-unlikely tails" Gaussian distributions exhibit.

Table 8: Model vs. Actual Delay Statistics

Overall Comparison of Model vs. Actual Program Delay in Months (1000 Simulations vs. 33 Programs)				
	Min	**Max**	**Average**	**Std Dev**
Model Results	0.00	66.79	18.62	11.58
Actual Results	0.69	44.11	18.82	12.08
Difference	N/A	34%	1%	4%

The histograms of the model and actual data provide a visual comparison of the respective distributions. Both distributions appear to display a bi-modal nature. Actual data appears to have modes at roughly 2 and 20-30 months, while the model outputs modes at 2 and 10-20 months, albeit with a larger tail. Possible reasons for this bi-modal nature are discussed in the following Results section. The model and actual program delay histograms are shown below in Figure 6.

Finally, a two-sample KS test was performed to test for like distributions between model and actual data. A KS test is a nonparametric test used to compare a sample's empirical distribution function (EDF) to a reference CDF. The KS test is sensitive to differences in both the location and shape of the concerned distributions (Justel, Pena, & Zamar, 1997). In this case the simulated data was treated as the reference CDF. The actual overall program delay data was the sample EDF. The KS test statistic quantifies the distance between the EFD's of both samples. The null distribution of the test statistic is calculated under the null hypothesis that both samples are drawn from the same distribution.

The KS test was run as a function within MATLAB software. The significance level was set at 0.05. The calculated test statistic was 0.1677, with a p-value of 0.3019. The result of this test failed to reject the null hypothesis that both samples are from the same distribution. The graphical result of the KS test is shown below in Figure 7.

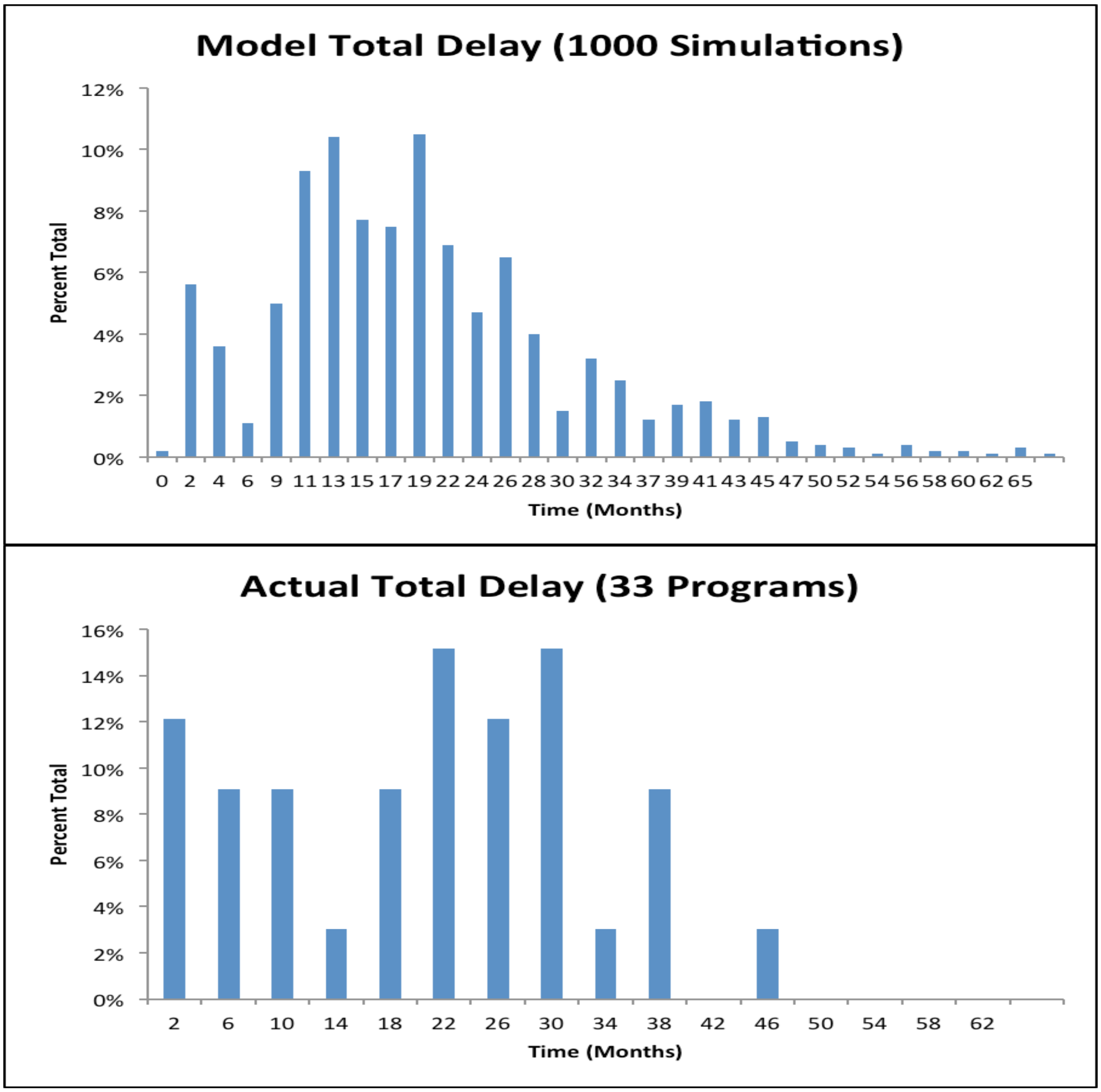


Figure 6: Model and Actual Histograms of Total Program Delay

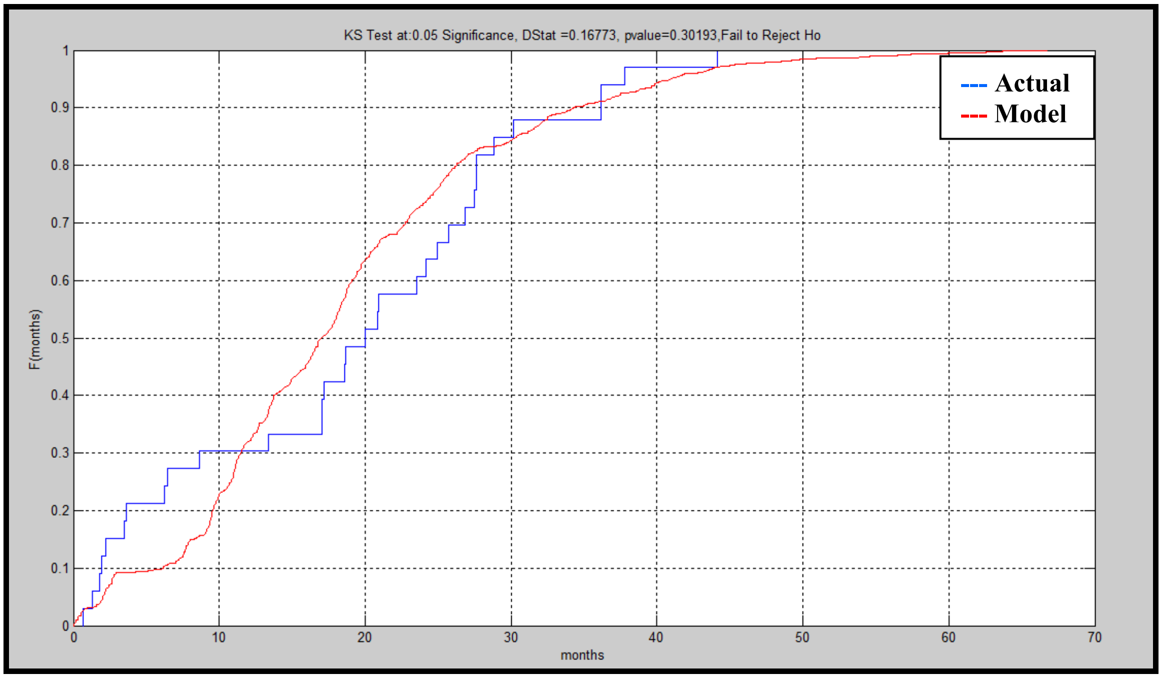


Figure 7: Results of KS Test for Like Distributions

IV. Results

In general the model shows an average delay beyond the program baseline schedule of 18.62 months. The delay most often experienced was 19 months, and 75% of programs experienced delays less than 25 months. Table 9 below shows the distribution of expected delays broken down by percentiles.

Table 9: Expected Delay By Percentile

Expected Delay vs. Percentile of Overall Programs (Months)						
	25%	**50%**	**75%**	**90%**	**95%**	**99%**
Expected Delay	<10.8	<17.0	<24.7	<34.4	<41.0	<54.6

As noted previously, the first finding was that no difference exists between Altas V and Delta IV launch vehicles with respect to schedule delays. This conclusion was based on statistical data collected from 33 historic launch schedules. While this initially surprised the research team, the data shows that delays within each of the seven delay categories can vary significantly for both vehicles and result in data groups that cannot be statistically separated. However, several trends were noted in the types of schedule delays.

Based on the delay category bins, LCRs submitted within those bins, and SME experience there are several issues that are often associated with schedule delays. The issues most often noted are multi-satellite procurements, varying technology risks, varying satellite complexity, contractor risk, and the confidence associated with original programmatic schedule estimates. Often, individual delays are unforeseeable and are caused by manufacturing issues or issues associated with another mission. A specific example is the Delta IV In-Flight Anomaly that occurred on the GPS IIF-3 that impacted

the launch timeline of the Orbital Test Vehicle (OTV-3) and a Space Based Infra-Red System (SBIRS) GEO-2 spacecraft (Headquarters Air Force Space Command, 2013).

As previously discussed, historical data also appears to exhibit some bi-modality. The team hypothesizes that this bimodality may be associated with a program's technology maturity, complexity, whether a specific mission is a first-of-a-kind or a multi-satellite constellation replenishment effort or whether there is significant urgency associated with a specific program. A relatively small number of programs cause the short-delay mode at approximately 2 months, and the experience of the SMEs has shown that programs even have the ability to accelerate if there is significant impetus and close coordination between all components of the acquisition process.

The average program experienced a delay of 18.82 months, but there appears to be a great variation dependent on the type of satellite program. Technologically mature programs face fewer threats to a schedule and therefore tend to have fewer slips in the integration, testing, and launch phases. In comparison, those space systems with significant complexity, either technological or integrative in nature, tend to experience significant delays in integration, testing, and launch.

Urgency of need has shown the ability to drive a program closer to an estimated schedule. This is primarily because Congressional and DoD leadership, the PPBE process, and the Government and Contractor acquisition processes are sometimes able to form a very tight team when national security is at stake. While this situation has been experienced by one of the authors of this paper, it is somewhat abnormal and occurs only when the direst of needs arises. Alternatively, basic constellation replenishment missions may have a higher tendency of being artificially delayed if the current constellation is

healthy. This priority shift then allows launch effort to focus on less healthy or higher priority programs.

The delay category appearing to have the most significant impact on a program's schedule is the "Space Vehicle – Early" delay. As previously described, the Space Vehicle – Early delay is initiated by the SV program office 18-months or more prior to the predicted launch date. At this point in an acquisition program significant fixes or changes may be incurred, usually extending schedules due to satellite disassembly, reassembly, test, and analysis involved in the specific resolution. While this delay occurs on average only 1.36 times per program, its overall time is the largest at 4.05 months per delay.

Alternatively, the team hypothesizes that satellite assembly, integration and test issues occurring late in a program have a significant time impact due their frequency of occurrence and "ripple" they induce in the overall launch process. "Space Vehicle – Late" delays occur on average 3.24 times per program but only incur 1.16 months per delay. More importantly, any delay within 18 months of planned launch has the potential to induce delays in another delay category, such as Priority or Re-Queue. This ripple effect can be largely eliminated if the initial SV delay is eliminated. Additionally, from a systems engineering perspective unforeseen issues late in a program tend to have much greater impact on cost and schedule than early delays.

The contribution of overall delay and occurrence by all seven delay categories is shown in Table 10 below. As mentioned above, SV Early delays contribute the most to the overall delay a program can expect to encounter, at 29.3%. In fact, as seen in Table 11 below, roughly half of all program delay (49.3%) is encountered due to the SV

program itself, while the other half is contributed by the launch vehicle or process. Additionally, it could be argued the Re-queue delay is in some cases due to a late SV program delay, hence increasing delay contributed by the SV program.

Table 10: Overall Delay Category Statistics

Overall Delay Category Statistics							
	SV-Early	**SV-Late**	**LV-Long**	**LV-Short**	**Re-queue**	**Priority**	**Wx/Misc**
Avg # of Occurrences per Program	1.36	3.24	2.21	1.70	1.67	0.79	0.82
% Based on Occurrence	11.6%	27.5%	18.8%	14.4%	14.1%	6.7%	6.9%
Avg Time Delay per Occurrence (Months)	4.05	1.16	1.57	0.56	1.99	2.07	0.18
% Based on Average Time per Occurrence	35.0%	10.0%	13.6%	4.9%	17.2%	17.9%	1.5%
Avg Total Time Delayed per Program (Months)	5.52	3.77	3.48	0.95	3.32	1.63	0.14
% Time Delayed per Program	29.3%	20.0%	18.5%	5.1%	17.6%	8.7%	0.8%

Table 11: Consolidated Delay Statistics

Consolidated Delay Statistics							
	SV-Early	**SV-Late**	**LV-Long**	**LV-Short**	**Re-queue**	**Priority**	**Wx/Misc**

	Satellite Vehicle	**Launch Vehicle or Process**
% Time Delayed per Program	49.4%	50.6%

	Satellite Vehicle	**Launch Vehicle**	**Launch Process or Range**
% Time Delayed per Program	49.4%	23.5%	27.1%

	Satellite Vehicle	**Launch Vehicle**	**Launch Process**	**Wx/Misc**
% Time Delayed per Program	49.4%	23.5%	26.3%	0.8%

V. Conclusion and Recommendations

The research team identified several recommendations for the space acquisition community. Based on SME discussions, current scheduling tools are fairly accurate; however the perception is that a realistic program schedule often dooms the program in terms of support. It is often assumed a realistic schedule may “scare” approving officials and potentially not receive funding and support. This leads to “green-light” schedules in an effort to compete with other programs for scarce resources. Ultimately, the original schedules may only be achieved if every aspect of the program goes smoothly, including the incorporated schedule margin. Often, a “green light” schedule is impossible even with perfect execution. Based on SME discussions and historical data, the probability of meeting a green-light schedule is practically impossible. The acquisition community must figure out how to overcome this culture. Four recommendations are provided below.

1) Programs can improve schedule estimates by utilizing current scheduling methods and incorporating an estimated delay within schedule margins. This delay should be based on the estimated average delay of 18.62 months, but increased or decreased based upon program-specific factors. These factors include learning curve incorporation of past lessons based on multi-satellite procurements, technology risks, satellite complexity, contractor risk, and the general risk posture associated with original schedule estimates. For instance, NRO satellites often push technological capabilities and are typically more complex than DoD communications satellites. As an example, a complex NRO satellite may be expected to have a longer schedule delay between Milestone C and launch than a DoD communications satellite has, such as Mobile User Objective System (MUOS).

2) Program Managers and schedule analysts should use system specific criterion such as Technology Readiness Levels (TRLs), relative experience level within the SPO and overall program scale to help estimate program timelines more accurately. Given these factors, a good starting estimate for program delay could range from 10 to 25 months, based on previously calculated delays for the middle 50% of programs.

3) In concert with increasing schedule margins to account for expected schedule delays, space programs should continue to assess a "green-light" schedule. Similar to the "will cost" vs. "should cost" estimation approach implemented across DoD acquisition, satellite acquisition offices should consider implementing two schedules, a "green-light" and "most-likely" schedule for senior leadership awareness (Tang, 20). Acquirers should vigorously pursue the "green-light" schedule with satellite contractors; however, leadership at all levels should be aware that these schedules are often unobtainable and that the "most-likely" schedule will best suit planning purposes for budgetary and requirements discussions.

4) Finally, the DoD and NRO should implement better practices for tracking historical program timelines and associated causes of delay. This data should be used to ensure lessons learned are properly vetted and passed between programs to alleviate schedule growth issues. Furthermore, future analysis similar to that conducted in this study can target specific areas for schedule improvement.

VI. Future Work

Future research recommendations include an in-depth validation of the entire ERAM model. While the space launch process model has not yet been fully incorporated into the ERAM model, it was built using the same tool, Extend Sim, with the intent of incorporating the post-Milestone C portion into ERAM. Issues noted in ERAM include an inability to easily model a negative delay, such as those seen due to priority shifts or accelerated timelines for satellite launches. Additionally, variable naming conventions used in ERAM, or lack-thereof, create difficulty when tracing simulation runs through the ERAM model. Lastly, per the recommendation of Extend Sim technical support, the overall ERAM model should be broken down into more manageable, modular pieces.

In the future, this model can be extended to encompass other launch vehicles such as the Delta II Medium Launch Vehicle or include future launch capability estimates for Space X, Orbital Sciences and other potential commercial launch vehicles. The inclusion of other launch vehicles may yield additional insight into contributing factors for delays. With this enhanced knowledge, specific actions can be taken to correct satellite acquisition schedules, which in turn, will significantly reduce costs.

There exists an opportunity for significant sensitivity analysis of the Space Launch model and its interaction across the DoD acquisition process. The research team recommends future research focus on adjusting the many variables within the model in order to minimize overall delay. The many variables include distribution parameters and probabilities of delay occurrence. Ideally, a variable may be found of which its adjustment will have a disproportionate effect on the overall delay. In addition, future research may focus on adjusting the delay categories or re-binning the individual delays,

in hopes of increasing the accuracy of the model. Additional research should be completed to find more complete documentation of program timelines and associated delays. Future assessments at the proper classification levels should be accomplished to enhance the opportunity to reduce program schedules.

Appendix A: Acronym List

AEHF	Advanced Extremely High Frequency
AFI	Air Force Instruction
AFIT	Air Force Institute of Technology
AFSPC	Air Force Space Command
CCAFS	Cape Canaveral Air Force Station
CDF	Cumulative Distribution Function
CLSRB	Current Launch Schedule Review Board
DoD	Department of Defense
DoF	Degrees of Freedom
DSCS	Defense Satellite Communications System
EDF	Empirical Distribution Function
EELV	Evolved Expendable Launch Vehicle
ERAM	Enterprise Requirements and Acquisition Model
FFRDC	Federally Funded Research and Development Corporation
GAO	Government Accountability Office
GEO	Geosynchronous
GM	Guidance Memorandum
GPS	Global Positioning System
GRP	Group Research Project
IC	Intelligence Community
ILC	Initial Launch Capability
ISS	International Space Station
KS	Kolmogorov-Smirnov
LCR	Launch Change Request
LCR	Launch Commit Review
LISN	Launch Information Support Network
LV	Launch Vehicle
MIT	Massachusetts Institute of Technology
MUOS	Mobile User Objective System
NLF	National Launch Forecast
NRO	National Reconnaissance Office
OTV-3	Orbital Test Vehicle-3
PDF	Probability Distribution Function
RCO	Rapid Capabilities Office
SBIRS	Space Based InfraRed System
SLM	Space Launch Manifest
SMC	Space and Missile Systems Center
SME	Subject Matter Expert

SOCOM	Special Operations Command
SPO	System Program Office
SV	Satellite Vehicle
TRL	Technology Readiness Level
ULA	United Launch Alliance
VAFB	Vandenberg Air Force Base
WX	Weather

Appendix B: Sample SME Discussion

SME Name/Position/Organization:
Interviewer:
Date:
Phone #:

1. Describe your roles and responsibilities in the Space Capability Development process?

2. If possible, please name the programs you've contributed to?

3. How early and where in your program's timeline was the launch capability/process integrated?

4. Have you witnessed a program delay solely due to the launch capability, vehicle, process, schedule, weather, etc? If so, please describe?

5. Does your organization attempt to model or account for potential program delays due specifically to space launch?

6. In your experience, where does a launch capability/process have the highest likelihood of affecting a space acquisition program?

7. How often has the space launch timeline been affected solely by your program? Please describe if able?

8. If possible, can you describe the duration and probability of launch related delays to a program?

9. Is there anything else you can add with respect to the effects of the launch capability/process on a space acquisition program?

10. Can you recommend any specific people we should interview with respect to program delays due to space launch (AFSPC, SAF/AQ, OSD or other agencies)?

Appendix C: ERAM 2.4 Configuration Changes

Enterprise Requirements Acquisition Model

Configuration Management Worksheet

This form provides a listing of the development and the changes done on the ERAM Simulation Model. Use the table below to provide the simulation software used (Arena or ExtendSim) , the new version number, the name of the author and corresponding organization, the date of revision and the description and purpose of changes.

Simulation Software	Source Version Number	New Version Number	Implemented By	Org	Date	Description of Change	Purpose of Change
Extensim	2.30	2.40	Auger, Baldus, Yoshimoto	United States Air Force Institute of Technology	04/16/13	- Added Space Launch model beneath the Rapid Acquisition model. - Changed file name to ERAM 2.4 04162013.mox - Changed Excel filename to ERAM 2.4 04162013 - Added Excel file “Space Launch data”. - Modified blocks 5823, 5571, 6071, 6098, 5539, 5990, 5992 to accommodate changes in Excel filename. - Added blocks 6434, 6440 to enable writing into Excel file “Space Launch data”. - Added tables “Run Space Launch” and “Space Launch Delays” to ExtendSim database to enable capturing of Space Launch data. - Added “Space Launch” input selector to Block 85, 5773, 5996, and the Excel Spreadsheet (column H). - Added “Buttons” to ExtendSim user interface for Space Launch relevant purposes. - Modified Block 358 to enable tracking of “# of runs” from the general ERAM model and exporting “Space Launch results” to the Excel file at the end of the simulation.	Accommodate Space Launch Process Delays add-ons

Bibliography

California State Polytechnic University, “Qualitative Research,” California State Polytechnic University Presentation, http://www.csupomona.edu/~smemerson/nbu-program-eval/trochimppp/Part%203/Qualitative%20Research.ppt. 28 May 2013.

Evans, Merran. and others. *Statistical Distributions*. 3rd ed. Hoboken: Wiley, 2000.

Government Accountability Office. *Defense Acquisition Assessment of Selected Weapons Programs.* GAO-06-391. Washington: GAO, March 2006.

Government Accountability Office. *Defense Acquisition Assessment of Selected Weapons Systems.* GAO-07-406SP. Washington: GAO, March 2007.

Government Accountability Office. *Defense Acquisition Assessment of Selected Weapons Programs.* GAO-08-467SP. Washington: GAO, March 2008.

Government Accountability Office. *Defense Acquisition Assessment of Selected Weapons Programs.* GAO-09-326SP. Washington: GAO, March 2009.

Government Accountability Office. *Defense Acquisition Assessment of Selected Weapons Programs.* GAO-10-388SP. Washington: GAO, March 2010.

Government Accountability Office. *Defense Acquisition Assessment of Selected Weapons Programs.* GAO-11-233SP. Washington: GAO, March 2011.

Government Accountability Office. *Defense Acquisition Assessment of Selected Weapons Programs.* GAO-12-400SP. Washington: GAO, March 2012.

Johnson, R. Burke, “Chapter 17, Qualitative Data Analysis,” University of South Alabama Lecture. http://www.southalabama.edu/coe/bset/johnson/lectures/lec17.pdf. 28 May 2013.

Justel, A., D. Pena, and R. Zamar. "A multivariate Kolmogorov-Smirnov test of goodness of fit." *Statistics & Probability Letters, 35(3)*: 251-259 (October 1997)

Milton, J. Susan, and Jesse C. Arnold. *Introduction to Probability and Statistics, 4th Ed.* New York: McGraw-Hill, 2003.

Montgomery, Jonathon A. *Expansion of Department of Defense Enterprise Requirements and Acquisition Model.* MS Graduate Research Paper, AFIT/ISE/ENV/12-J03. School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, June 2012.

Pawlikowski, Maj Gen Ellen. "Mission Assurance—A Key Part of Space Vehicle Launch Mission Success." *High Frontier*, Vol. 4 No. 4: 6-9 (August 2008)

Saxer, Col R.K., Lt Col J.M. Knauf, L.R. Drake, and Dr. P.L. Portanova. "Evolved Expendable Launch Vehicle System: The Next Step in Affordable Space Transportation," *PM*, 2-15: (March-April 2002)

Searle, Chad T., and David A. Leach. *Department of Defense Enterprise Requirements and Acquisition Model.* MS Graduate Research Paper, AFIT/ISE/ENV/11-J01. School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, June 2011.

United Launch Alliance. *Delta II Payload Planner's Guide.* Littleton: United Launch Alliance, 2006.

United Launch Alliance. "*Company History, Over 100 Years of Combined Launch History.*" Littleton: United Launch Alliance, 2013. http://www.ulalaunch.com/site/pages/About_ULAHistory.shtml

Wirthlin, J. Robert. *Identifying Enterprise Leverage Points in Defense Acquisition Program Performance.* PhD thesis. Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, MA, September 2009.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704–0188

1. REPORT DATE (DD–MM–YYYY) 13-06-2013	2. REPORT TYPE Graduate Research Paper	3. DATES COVERED (*From — To*) May 2012 – 13 Jun 2013

4. TITLE AND SUBTITLE Modeling Space Launch Process Delays To Improve Space Vehicle Acquisition Timelines	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Baldus, Lars, Lt Col Yoshimoto, Brian K, Maj Auger, Christopher M, Maj	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Institute of Technology Graduate School of Engineering and Management (AFIT/ENY) 2950 Hobson Way WPAFB OH 45433-7765	8. PERFORMING ORGANIZATION REPORT NUMBER AFIT-ENV-GRP-13-J-01
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) United States Naval Post-Graduate School Keith F. Snider, PhD Graduate School of Business & Public Policy 555 Dyer Rd Monterey, CA 93943 Comm: 831-656-3621, Email: ksnider@nps.edu	10. SPONSOR/MONITOR'S ACRONYM(S) NPS/BPP 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A: Approved For Public Release; Distribution Unlimited.

13. SUPPLEMENTARY NOTES This material is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

14. ABSTRACT
United States Department of Defense (DoD) space acquisition programs often experience significant schedule growth. Even with the advent of reliable launch vehicles, schedule delays often exceed 3 years and have the implication of reduced military or national security capabilities, significant increases in costs and occasionally program cancellations. This paper gives acquisition professionals insight into the DoD's space launch process through modeling and simulation. It discusses reasons a model is needed, outlining the perceived causes and resulting impacts of significant schedule growth between planned and actual launch dates. This paper scopes the problem into a practical area of research, specifically from Milestone C through launch. Significant drivers to space vehicle timelines are the processes associated with scheduling launch support and conducting integration efforts for launch processing. Seven causal factors are identified, analyzed and assessed to draw conclusions about schedule growth and timeline considerations. The authors discuss the implications of these factors and hypothesize about lower-level contributors to create recommendations for those involved with space acquisitions. Recommendations are provided focusing future research towards the identification of specific actions which may reduce schedule delay incurred within the space launch process.

15. SUBJECT TERMS
Space Launch, Schedule Delay, Simulation, Process Modeling

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Dr. John Colombi
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	UU	53	19b. TELEPHONE NUMBER (Include Area Code) (937) 255-3636, ext 3347 john.colombi@afit.edu